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Deposited in DRO:

22 February 2013

Version of attached file:

Accepted Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Beck, Anthony R. and Philip, Graham (2013) 'The archaeological exploitation of declassified satellite photography in semi-arid environments.', in Archaeology from historical aerial and satellite archives. , pp. 261-278.

Further information on publisher's website:

<http://dx.doi.org/10.1007/978-1-4614-4505-0>

Publisher's copyright statement:

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14. The archaeological exploitation of declassified satellite photography in semi-arid environments

[Pre-print](#)

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Abstract

Declassified satellite photographs are becoming an increasingly important archaeological tool. Not only are they useful for residue prospection and, when in stereo pairs, Digital Elevation Model (DEM) generation, they can also provide large scale temporal snap-shots that provide essential information on landscape change. Importantly, in some instances, declassified photographs may be the only available record of archaeological residues that have subsequently been eradicated.

This chapter outlines a generic approach to accessing, digitising and processing declassified satellite photographs and utilising them in conjunction with modern fine resolution satellite images. The methodological issues of acquisition and pre-processing are addressed. A number of potential archaeological applications are described and illustrated with examples from the Settlement and Landscape Development in the Homs Region, Syria (SHR) project. These examples demonstrate that there is no single approach to processing and image selection. Rather, processing is dependent upon the nature of the archaeological residues and their surrounding matrix, the type of analysis one wants to undertake and the range of ancillary datasets which can be used to ‘add value’ to the source data.

Introduction

Aerial photography is the oldest form of remote sensing in archaeology. Historically, bespoke archaeological remote sensing has been based on low altitude aerial survey using handheld cameras with films sensitive to the optical and near infra-red (Wilson 2000). However, traditional aerial photography is not without its problems. The reliance on a small component of the electro-magnetic spectrum raises a number of issues. The small spectral window can induce a significant bias as only certain residues under specific conditions express contrasts in these wavelengths (for example aerial photography in the UK is broadly recognised not to work in clay environments). In areas that have been intensively studied, such as the UK, a point of saturation can be reached. This could mean that increasingly extreme environmental conditions may

be required to detect new archaeological residues (with climate change, this may be an unfortunate reality). On a more pragmatic note, some countries operate a closed skies policy or impose severe bureaucratic challenges in obtaining the necessary permits. Finally, traditional archaeological aerial photography collects many localised photographs in a predominantly unsystematic way influenced by what is seen by the observer (Cowley 2002).

Photographs and digital images¹ collected from a satellite platform has the ability to address a number of these drawbacks. Satellites, by their very nature, represent open skies collection systems and can have fine resolving characteristics (Fowler 2004 and this volume). Furthermore, in common with conventional aerial imaging, satellite images have a large synoptic footprint and are therefore more systematic and exhaustive approaches to survey.

Archaeologists were quick to spot the potential of the first public Earth observation satellites in the 1970s (e.g. Lyons and Avery 1977). Initially, however, imagery from publically available sensors, such as Landsat, was not only expensive but had a ground resolution which was too coarse for thorough archaeological prospection. Though archaeological features could be detected, the vast majority were already well documented. This situation changed in the mid 1990s for two important reasons: the declassification of high resolution photographs by the American and Russian governments and the deregulation of commercial remote sensing systems allowing the collection of sub-metre resolution images. The availability of images with a ground resolution approaching that of traditional aerial photographs had the potential to revolutionise archaeological prospection. This is particularly true for areas where the archaeological resource is poorly understood or documented.

In the nearly 15 years since the first ‘spy’ satellite photographs were declassified there has have been several changes, including the declassification of other programmes, a better understanding of the potential of the resource and improvements in how the resource is accessed and disseminated. This chapter aims to provide an overview of the processing and applications of declassified satellite imagery for archaeological purposes, with descriptive exemplars from a semi-arid environment.

Declassified satellite photography

At the start of the ‘cold war’ both the American and Russian governments conducted photographic reconnaissance from manned ‘spy’ planes and unmanned adapted V-2

rockets. Between the 1960s and the early-1990s researchers in each country developed dedicated military reconnaissance systems. Initially, these systems were camera based, requiring short-term missions (days to weeks) and an ability to re-deploy captured photography back to earth. From the mid 1970s the US military adopted electro-optical imaging for new programmes. These sensors could be placed in stable orbits and the digital images were electronically relayed to earth. The level of secrecy was extremely high and all the resultant photographs and images were classified (Kramer 1996).

In 1992 Russia started selling selected photographs from their fine resolution (2m) KVR-1000 camera. In February 1995 President Clinton declassified the first generation of American reconnaissance satellites (programmes active between 1960 and 1972), with a second round of declassification in 2002 (Fowler 2004 and this volume). Though the following sections focus on the use of American declassified satellite photography from the CORONA programme available from the United States Geological Survey (USGS), whose characteristics are summarised in Table 14.1, the majority of the processing techniques described are generic and would apply to other declassified image sets (such as the Russian KVR-1000 imagery) or to any photographic datasets that may be declassified in the future.

Digitising declassified photography

Although most users will purchase pre-digitised satellite photography through the USGS EarthExplorer web interface (<http://edcsns17.cr.usgs.gov/EarthExplorer>), some may want to digitise copies of film sourced from the National Archives and Records Administration (NARA). Alternatively, other ‘spy’ satellite programmes may be declassified in the future and only made available as film that requires digitising. As it is likely that the resultant digital facsimile will be employed in a variety of quantitative processes the spatial and radiometric fidelity of the scanning process is of paramount importance. For example, if one wanted to generate stereo elevation models then a high quality initial scan is essential. Therefore, one should determine an appropriate scanning methodology appropriate for any subsequent analytical tasks (Philip et al. 2002a; Ur 2002).

For example, on the project Settlement and Landscape Development in the Homs Region, Syria (SHR), described below, the following approach was taken. The project team wanted to generate elevation models and conduct other quantitative analyses on

the CORONA imagery and hence required a high quality digitising process. As the CORONA photography has a nominal resolution of 160 lp/mm (see Table 14.1) a full resolution scan would require a 3 μ m (c. 8000 dpi) scanner. The most appropriate available option was a high resolution photogrammetric scanner (a Vexcel VX4000). This scanner has a high resolution (7.5 μ m) scan head without interpolation, a geometric accuracy of 1/3 pixel RMSE and a radiometric accuracy (in 8 bit) of 2 digital number RMSE. The resultant imagery had a nominal ground resolution of approximately 2m.

Geo-referencing declassified imagery

Prior to any rectification or data collection procedure a projection system must be determined. In most areas that have institutionalised Cultural Resource Management (CRM) bodies the regional or national projection system is easily accessible. It is advisable (and in some instances mandatory) that this projection system is used. This will ensure that any results will integrate seamlessly with the national CRM data and other datasets enabling subsequent data re-use and integration (Bewley et al. 1999). Where such a system does not exist then it is advisable to use one of the standard worldwide referencing systems such as Universal Transverse Mercator (UTM) or Lat/Long projections (both standard worldwide reference projections) and an appropriate datum (if in doubt use WGS84).

UTM is more intuitive for in-field work than Lat/Long (units are metres as opposed to seconds of arc) and is in use within many CRM databases (cf. Palumbo 1992).

Rectification is the process of correcting systematic and random errors in imagery. Rectification procedures can either be spatial, to geo-locate an image, or non-spatial, to remove scanning or camera aberrations. Spatial rectification relies on the ability to recognise objects within the imagery that have known co-ordinates. These objects are referred to as Ground Control Points (GCPs) or tie-points. These points can be derived from topographic mapping, Global Navigation Satellite Systems (GNSS: such as GPS) or other remote sensing imagery. It is advisable to employ only a single data source as otherwise complicated error propagation issues could arise.

As declassified imagery is, by necessity, historic, there are likely to have been a range of different modifications that can make GCP identification ambiguous. In this respect the use of remote sensing images as a rectification source has significant advantages:

the interpreter is aware of the localised context of any GCP and can make a value judgement on quality and fitness for purpose.

Prior to rectification, the spatial accuracy requirements of the resultant image must be established. The accuracy is dependent upon the end-use of the imagery. If the aim of the geo-referenced image is to facilitate detection, characterisation and approximate location, then high positional accuracy is not required. However, if mapping is derived from the imagery then high positional accuracy is required in order to ensure that the mapping and field survey results correlate.

Finally, co-registration issues should be considered. Co-registration is the geo-referencing of two different images so that each overlaying pixel corresponds to the same location. Due to the errors associated with rectification it is rare for this to occur by accident. Accurate co-registration is important for some time change analyses and photogrammetric extraction of elevation models from stereo pairs.

For the SHR project the declassified photography was geo-referenced using 1m ground resolution Ikonos imagery as a reference source. The comparable spatial resolution of the imagery allowed the confident determination of appropriate tie-points. The reported nominal accuracy for the Ikonos Geo-product TM was 23.3m (Gerlach 2000): empirical GPS field measurements confirmed this value.

Rectification trials using GPS tie-points derived from points of hard detail (such as bridge and road junctions) produced better accuracy rectifications. For stereo-pairs the second image was co-registered directly to the contemporaneous primary image.

The archaeological application of declassified photography

Fine spatial resolution declassified satellite photography has a number of archaeological applications. The primary one is that of archaeological prospection, for which, due to destructive modification, historic photography may be the only available resource. However, there are also other reasons for using such imagery. Many declassified satellite programmes had stereoscopic viewing capabilities. This allows the generation of elevation models. These may allow the identification of archaeological phenomena not directly visible in the photograph (for example, hollow ways and other subtle topographic features). The fact that the imagery is historic can provide insights into any modifications that have occurred within the landscape and potentially quantify their impact on the archaeological resources. Time change analyses can also reveal other important environmental and anthropogenic factors that

may impact on the management of the cultural resource. Finally, one should not underestimate the use of digital imagery for site navigation and field interpretation. When imagery is incorporated within a GIS based recording and curation system a number of synergies can be exploited. For example, when in the field, access to an overhead perspective of the residues can significantly clarify contextual ambiguities and improve recording and interpretation.

Archaeological prospection

Unlike the majority of mainstream remote sensing specialists, archaeologists cannot rely on explicit spectral signatures to identify archaeological residues. Rather, it is hypothesised that archaeological residues produce localised contrasts in the landscape matrix which can be detected using an appropriate sensor under appropriate conditions. Although this statement sounds self evident it requires an understanding of the dynamics of both the nature of the residues and the landscape matrix within which they reside.

Once this data has been acquired then physical, chemical and biological models can be developed to help understand how archaeological contrast may be expressed in different areas of the electro-magnetic spectrum and under what conditions this contrast is most identifiable. With these models one can then determine what type of sensors have the resolving capacity to detect identified contrasts. An appropriate sensor is one which has the following appropriate characteristics:

- Spatial resolution that allows the interpreter to identify the spatial structure of the object;
- Spectral resolution that records reflectance in the area of the electromagnetic spectrum where the contrast is expressed;
- Radiometric resolution that has the sensitivity to discriminate the contrast difference between the object and its surrounding matrix;
- Temporal resolution that collects the imagery when the contrast is expressed.

Spatial and spectral resolution is generally well understood by an archaeological audience. However, radiometric and temporal resolutions require further explanation. Radiometric resolution is particularly important for prospection as it describes the subtlety of the sensor measurements which, in part, determines whether an object can be detected. For example, if two panchromatic sensors with exactly the same spatial

and spectral resolution, but different radiometric resolutions, take a digital image of the same object from the same location (within the shadow of a building) at the same time, only the sensor with the finer radiometric resolution can be used to differentiate the object from the shadow. However, because under normal viewing conditions the human eye can discriminate only between 20 to 30 shades of grey², it is unlikely that the brain would be able to detect the object even though it exists numerically within the structure of the data. It is only with appropriate contrast manipulation of the finer radiometric resolution image that the object becomes apparent. This is analogous in trying to detect centimetre variations with one ruler that rounds measurements to the nearest millimetre and a different ruler that rounds measurements to the nearest decimetre. As archaeological residues commonly represent subtle shifts in reflectivity, much important archaeological information contained within an image can often go undetected.

Temporal resolution refers to how often a sensor system records a particular area. For all platforms except satellites in a fixed orbit this value is likely to be infrequent. However, satellite images tends to cover the same area at the same time of day, whereas all other sensor platforms can cover an area at different times of day. This is particularly significant for some forms of contrast which occur at different times of day (such as shadow marks or diurnal temperature variations) or under specific, temporally constrained, conditions.

For declassified imagery purchased directly from USGS all the axes of resolution are constrained. The temporal resolution is fixed: the majority of CORONA and GAMBIT mission were in sun-synchronous orbits with local collection times of between 10:00 and 14:00. However, some missions were scheduled at different times to exploit specific phenomena. The spatial resolution is dependent on the platform, camera system, orbital characteristics and scanning technique, but for CORONA KH-4b it is nominally 2m. The spectral resolution varies with the film which is generally agreed to be sensitive to the visual and near-infrared wavelengths. The radiometric resolution is a function of the film and scanning process. For USGS imagery this is 8 bit or 256 distinct values. However, the film has a nominal 12 bit (4096 value) depth (USGS pers. comm.) and Leachtenauer et al. (1998) have scanned film at this detail. Hence, there is data loss in the digital USGS product due to the scanning process.

The ‘Settlement and Landscape Development in the Homs Region, Syria’ (SHR) project

The previous sections have discussed some of the technical details surrounding the photographic sensors, data acquisition, data processing. The following section describes the use of declassified satellite photography on one project in Syria. Though the utility of declassified satellite photography in the region has been demonstrated by several authors (Kennedy 1998; Kouchoukos 2001; Stone 2003; Ur 2003 and 2005; Challis et al. 2004; Challis 2007), The SHR project was one of the first projects to conduct in-depth research into the archaeological potential of fine (high) spatial resolution satellite imagery. Declassified photography, particularly CORONA imagery, has played a pivotal role in the detection, interpretation, management and long term understanding of the different archaeological landscapes in the SHR environs.

In common with many other areas of the world the SHR project is working in a data-poor environment. The extant archaeological inventory for the study area is biased towards large ‘monumental’ archaeological sites, such as tells (Rosen 1986), a settlement form characteristic of many parts of the Middle East. Other, generally smaller, settlement and land management components of the landscape are under-represented. Furthermore, although available, there was difficulty in acquiring appropriate data sets which are commonly used to contextualise interpretations, such as contour, topographic and soil maps. Following preliminary field visits a remote sensing programme was introduced in 1999 to identify archaeological residues as part of a site prospection programme and to generate landscape themes that were previously unavailable to the project.

All reasonable quality CORONA KH-4b mission photographs intersecting the study area were purchased prior to analysis. As the photographs were going to be used for a range of quantitative applications including DEM extraction, the digitising strategy described earlier was adopted. The resultant CORONA images were used in conjunction with bespoke high resolution panchromatic and multispectral Ikonos satellite images. The time frame for Ikonos data capture was determined for each environmental zone independently based upon models of peak archaeological contrast. The pre-purchased CORONA imagery was particularly useful for testing model validity. Finally, it must be emphasised that, although CORONA is a useful tool in its own right, its full potential was only realised when used in conjunction with the more recent Ikonos images.

The environmental makeup of the Homs region

The SHR project was designed to investigate long-term human-landscape interaction in adjacent but contrasting environmental zones, located in the upper Orontes Valley near the present-day city of Homs, Syria (Philip et al. 2002b; Philip et al. 2005; Beck et al. 2007a). Each zone is typical of a larger area, and initial study suggested that they differed substantially in both their settlement histories and in the nature of their archaeological records. There are two principal zones, basalt (140km²) and marl (370km²). The marl zone is a relatively flat landscape developed on lacustrine marls of Upper Miocene-Pliocene date (Wilkinson et al. 2006). It is an eroding terrace sequence sloping down to the river Orontes (Bridgland et al. 2003). Aggradation in this zone means that the majority of archaeological residues will be on or very near the surface (Wilkinson et al. 2006). The only buried deposits are likely to be under tells or other areas of long-term occupation. The basalt zone has a series of low boulder-strewn plateaus, interspersed with shallow colluvium-filled valleys and depressions. Since the mid-1970s the region has experienced moderate expansion of settlement. Of greater impact has been the use of agricultural machinery: the deep plough in the marl zone and the bulldozer to clear fields in the basalt zone.

In the marl zone the majority of the archaeological residues take the form of tells and low relief soil mark sites (Fig. 14.1: 197, 256, 308, 454). Tells are prominent landscape features and, unless heavily eroded, are easy to detect, so that the majority have already been mapped and recorded. These reflect mainly the settlement record of the Bronze and Iron Ages. On the other hand soil mark sites, many of which date between the Hellenistic and Islamic periods, are very difficult to spot on the ground and, when identified at all, have traditionally been located using intensive surface survey programmes.

In the basalt zone the archaeological residues take the form of cairns, field walls and concentrations of rubble which constitute the remains of abandoned structures (Fig. 14.1: A, B, D). For an initial morphological classification of such structures see Philip et al. 2005). The smallest of these features are stone alignments with a width of less than 1m, which in some cases, may project only a few tens of centimetres above the present ground surface.

Prospection in the basalt zone

With comparatively stable soils with little indication for either soil erosion or sediment aggradation, the basalt zone contains a complex multi-period palimpsest of archaeological structures. Features are primarily constructed from locally sourced basalt (i.e. they have a similar spectral signature to the background basalt soils). In order to detect archaeological features in this environment the following are relied upon: topographic effects, which might produce contrast through shadows; and spectral response, in the form of tone or texture differences between structures and soil or vegetation.

The width of the smallest archaeological features (c. 0.5m) necessitated the use of fine spatial resolution imagery. For the mapping of small features, such as field walls, image fidelity needs to be high. Hence, the summer months (May to September) were to be avoided, when airborne particulates increase specular reflection and, therefore, decrease spatial resolution.

Residue detection in the basalt zone was relatively straightforward (Fig. 14.2). Even though the smallest feature size was much less than the resolving power of the sensors, the structural continuity of features and shadows meant that features were readily detectable. Both the CORONA and Ikonos imagery were used for visual interpretation and mapping. Due to its finer spatial resolution the pan-sharpened Ikonos imagery provided the best resource for mapping. Metric measurements and identification were also more accurate. However, there were fewer landscape modifications of the kind that were likely to hinder interpretation in the CORONA imagery. The synergies obtained by using both data sources together confirms that in combination they provided a better resource for archaeological interpretation than did either dataset alone.

The benefits of temporal resolution in the basalt zone

The basalt zone is a landscape which is under significant threat. In the past 30 years, enhancements to the road and rail networks, and the concomitant increase in associated settlement activity (cf. Sever 1998), have removed archaeological features. Even more significant is the clearance of fields, walls and cairns by bulldozing as part of agricultural improvement schemes. Hence, historical imagery provides a view of the basalt zone prior to modern destruction (Fig. 14.1). The CORONA imagery predates the major phase of bulldozing and has recorded a landscape with minimal

destruction, disturbance or masking of archaeological residues by present day agricultural or settlement expansion. This is a potentially fortuitous set of circumstances as the application area lies in a region which was considered militarily sensitive and over which a relatively large number of CORONA missions had been flown.

Improving geo-referencing accuracy

The basalt zone represents a complex palimpsest containing many archaeological residues in close proximity. The result was that even using hand-held GPS and a print-out of CORONA or Ikonos imagery, surveyors found it nearly impossible to establish a one-to-one correspondence between the majority of features appearing on the imagery and those visible on the ground. Thus, while CORONA offered a useful means of mapping the landscape as a whole, its value for more localised survey was constrained because of the difficulty of feature identification. A way needed to be found to improve the spatial accuracy of the Ikonos and CORONA rectification. Fraser et al. (2002) demonstrated that the positional accuracy of the Ikonos Geo-product™ could be increased to sub-metre levels by using tie-points located by Differential GPS. Using handheld GPS the Ikonos imagery was re-geocorrected with a nominal accuracy of 5-8m. The CORONA imagery was georeferenced to this re-rectified Ikonos retaining approximately the same error. The resulting greater degree of accuracy in the imagery allowed desk-based mapping and subsequent field navigation to be undertaken with improved confidence. It is clear from Figure 14.2 that accurate geo-referencing is required in order to re-locate digitised features due to their sheer number in the basalt zone.

Prospection in the marl zone

In order to detect the archaeological residues it was necessary to understand not only how any contrast would be expressed, but also the physical causation of that contrast. The rationale was to ensure that the imagery collected provides the maximum observable information for the phenomena of interest. It was postulated that these sites represent the decayed and thoroughly ploughed remains of abandoned settlements originally composed of mudbrick structures (Wilkinson et al. 2006). If this were the case then the soil associated with each archaeological site could in theory be differentiated from the localised soil by some difference in grain size, structure,

moisture content or chemical/biological composition due to the degraded building material. It seems reasonable to suggest, therefore, that this might give rise to differences in soil and/or crop properties that ought to be detectable using satellite imagery.

It was noticed that each site exhibited a subtle soil colour difference. When compared against a Munsell chart, it was established that, when dry, archaeological residues were significantly lighter in colour (reflecting an increase in chroma) than the surrounding off-site soils, but that on and off site soils were indistinguishable by eye when wet (demonstrating that both soils share the same parent regolith). The inspection of CORONA imagery from different seasons revealed that the colour differences between archaeological and non-archaeological soils were most evident during peak aridity (September and January), although sites were also readily detectable during periods of drying-out following rainfall. This presumably reflects differences in the moisture retention capacity of archaeological soils which will be a function of grain size and organic content. This simple observation provided enough information to determine that for optical satellite imagery the archaeological residues in the marl zone would exhibit the most contrast during periods of peak aridity.

Further in-situ and laboratory analysis was undertaken which confirmed this hypothesis (Wilkinson et al. 2006; Beck et al. 2007b; Beck 2007).

Hence, the ideal time for image collection would be between September and January when the soil is either arid or hyper-arid. The problem with this time frame is that there are a range of airborne particulates which could decrease image fidelity. These particulates would be reduced during the winter rains, which tend to start in December.

Archaeological residues in the marl zone take the form of discrete settlement sites that are easy to identify as colour or textural variations in soil (Fig. 14.1: flat sites 197, 308 and 454). Both the Ikonos MS and CORONA are particularly useful resources for displaying changes in soil colour. These residues are an order of magnitude larger than those found in the basalt zone. Hence, there is not such a reliance on high spatial resolution data. There is more scope for interpretation by proxy in this zone. Some sites are associated with kinks in the road network, where the road respects the archaeological site. These are useful indicators when interpreting the satellite imagery. Since the CORONA photographs were obtained this zone has been subject to a range of landscape modifications, but due to the nature of the residues few sites have

been eradicated. Rather, deeper ploughing has removed some of the surface textural components in the Ikonos imagery and brought sub-surface marl deposits to the surface, creating a number of potential but negative features. Hence, using CORONA and Ikonos in combination generates a number of synergies which result in a more confident interpretation of the marl landscape.

Generating DEMs from CORONA for the Homs region

Galiatsatos and co-workers (Galiatsatos 2004; Galiatsatos et al. 2008) extensively discuss the creation of DEMs by photogrammetry using a CORONA - CORONA stereo pair. Galiatsatos extracted the DEM using traditional photogrammetric techniques. Like Altmaier and Kany (2002) an empirical non-metric camera model was employed.

Even considering the distortions introduced by the panoramic KH-4b camera system, Galiatsatos achieved DEM accuracies approximating to 5 metres in all three dimensions and a ground resolution of c. 17m. The increased accuracy and resolution means that DEMs derived from CORONA imagery can be applied to more sophisticated archaeological problems, such as the identification of wadi channels by modelling surface deformation. Interestingly, Galiatsatos (2004) proposes that stereo models using historic and modern images as stereo pairs can be used for time change analysis. He postulates that if one were to analyse the error surface associated with the DEM then locations with large errors will be due to changes (such as house construction). Finally it should also be noted that the declassified KH-7 GAMBIT and KH-9 HEXAGON have stereo capabilities and camera systems that introduce fewer distortions than CORONA. However, the archaeological applicability of DEMs from these sensors have yet to be evaluated.

Discussion and conclusions

CORONA photographs in conjunction with Ikonos images have provided a wealth of new archaeological information for the area around Homs, Syria. The differences between the two environmental zones and the nature of the archaeological residues mean that different approaches are required for image capture and processing in order to extract the maximum archaeological information. To aid image interpretation, keys for the different zones have been produced (e.g. Fig. 14.3).

In the marl zone the re-incorporation of degraded mud-brick building material gave rise to changes in the moisture content, grain size and structure of the soil at the site. Having an understanding of the physical nature of this archaeological deformation process allows one to determine what types of sensing device, or other detection technique, and what conditions are appropriate for identifying this contrast. In this instance the localised reflectance difference expressed in the optical wavelengths was used. In order to achieve the maximum contrast for the archaeological residues dry soils with limited crop cover were required. This choice of conditions and contrast type was determined by the detecting sensor – an optical sensor was employed so contrast differences expressed in the optical region are required. However, the modelling suggested that sensors in the Short Wave Infra Red (SWIR) may be more sensitive to variations in mineralogy and structure. This knowledge can be used to enhance the visualisation. Once it was understood that in the optical wavelengths sites did not produce a specific spectral signature, but rather a relative shift to the spectral curve, bespoke enhancement algorithms were developed (Beck et al. 2007b).

Different techniques are required in the basalt zone, where archaeological are substantially smaller than in the marl zone. The CORONA images provides a synoptic view of the landscape prior to recent destructive modifications. However, the Ikonos images produces a less generalised view of the archaeological residues allowing improved detection and interpretation. When the Ikonos and CORONA images are used in conjunction with one another further benefits are realised. From a Cultural Resource Management perspective the analysis of both data sources provides an overview of the archaeological residues and the range and number of destructive modifications over the past thirty years.

The accurate rectification of the Ikonos and CORONA data employed in the basalt zone has provided the level of spatial control that could only otherwise have been obtained using a Total Station or DGPS survey, a technique which would have been vastly more time-consuming for an area of this size. It is important to note, therefore, that without using the Ikonos images as a basemap, it would have been nearly impossible to rectify the older CORONA data to an acceptable level of precision. Using Ikonos images, the rectification of CORONA became a desk-based, rather than a field procedure, a routine that offers obvious economies of both time and money. Thus, in

addition to its inherent value as high quality imagery with fine spatial resolution, Ikonos considerably increased the usability and value of the older CORONA data. In this environment the satellite imagery has framed the survey programme by locating ‘peaks’ of archaeological activity. Hence, resources can be efficiently deployed during field seasons resulting in improved modes of data collection and analysis. Importantly, the project team determined that satellite imagery detected the majority of surface residues. That said, a degree of ‘off-site’ sampling is required to provide some control over classes of feature which may not be readily detectable using imagery, or to identify any landscape types in which the presence of archaeological material does not generate the kinds of indicators discussed above. This chapter has outlined a generic approach to accessing and digitising declassified satellite photographs, highlighted some of the potential archaeological issues to which these photographs can be applied and illustrated this with examples from the SHR project. These examples demonstrate that there is no single approach to processing and image selection. Rather, processing is dependent upon the type of analysis one wants to undertake and the range of ancillary datasets, such as present day imagery, or devices, such as GPS, which can be used to ‘add value’ to the source photographs. Image selection is a critical part of the process and requires an understanding of the nature of the archaeological residues, the localised contrasts they may exhibit and how these contrasts may vary over time.

Declassified photographs are a good resource in their own right, but their value is enhanced when they are utilised with other datasets. Particular synergies are observed when declassified photography is used with modern fine resolution satellite images (such as Ikonos or Quickbird). At a practical level modern images provides a more robust reference source for geo-referencing. From a prospection perspective the combination of modern and historic images offers many benefits. The value of historic data in areas where recent change has removed or obscured archaeological evidence is obvious.

Declassified satellite photographs are becoming an increasingly important archaeological tool. Not only are they useful for residue prospection and, when in stereo pairs, Digital Elevation Model (DEM) generation, they can also provide large scale temporal snap-shots that provide essential information on landscape change. Importantly, in some instances, declassified photographs may be the only available record of archaeological residues that have subsequently been eradicated. Future

declassification of other 'spy' satellite programmes, some with even higher spatial resolution, will provide greater granularity to this temporal sequence.

Acknowledgements

The authors gratefully acknowledge the support provided by the Natural Environment Research Council to Beck through Award Ref. GT0499TS53 and for the purchase of the Ikonos imagery by their Earth Observation Data Centre. Thanks are due to Nikolaos Galiatsatos for help provided during the writing of this paper. The Ikonos imagery includes material © 2003, European Space Imaging GmbH, all rights reserved. CORONA and GAMBIT data compiled by the U.S. Geological Survey. We also wish to thank the British Academy and the Council for British Research in the Levant for their financial and logistical support of our fieldwork. All illustrations have been produced by the first named author. Thanks are also due to the Directors and staff of the Damascus and Homs offices of the Directorate General of Antiquities and Museums, Syria for all their help and assistance during the field seasons, with particular thanks due to our collaborators: Dr. Michel al-Maqdassi, Director of Excavations DGAM Damascus and Engineers Farid Jabbour and Maryam Bshesh of the DGAM office in Homs.

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Footnote

1. Photograph is used explicitly throughout this chapter to refer to a film (analogue) product. The term image refers explicitly to a digital product.
2. This figure is under debate. However, it is true to say that the brain can distinguish far fewer shades of grey than colours.